MRB-CMC internal seminars

28 Jan. 2005 11h00

Atmospheric CO_2 retrieval from the AIRS and AMSU instruments onboard AQUA

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PRESENTATION OUTLINE

-Why is it interesting to measure CO_2 from space ?

-Which instruments are available for this purpose ?

-Presentation of the AIRS and AMSU instruments

-Radiative transfer, principles of atmospheric sounding

-Description of the retrieval method

-First results

-Conclusion, perspectives

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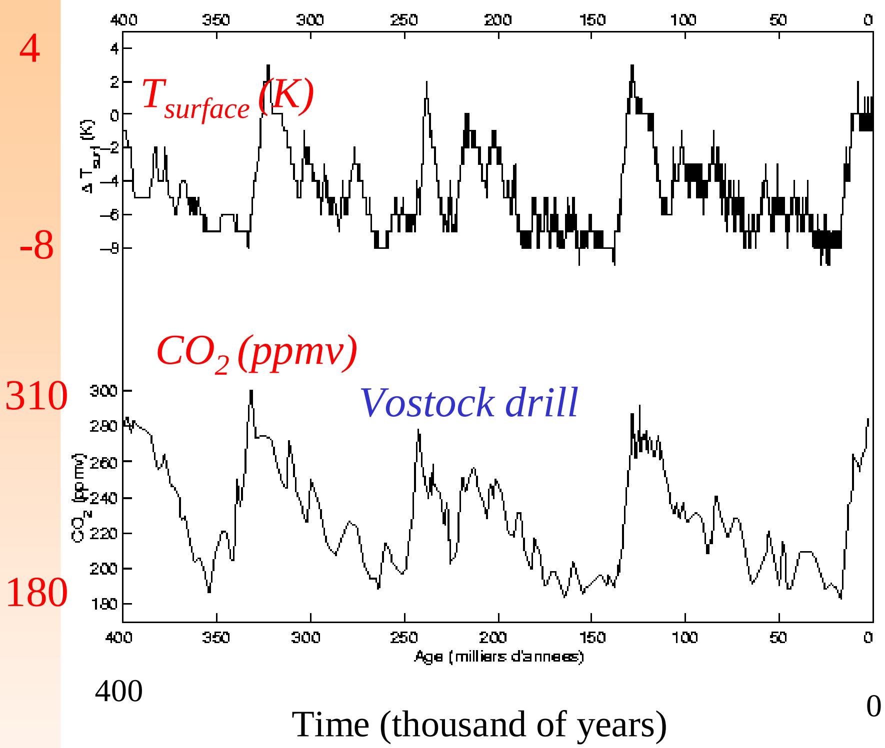
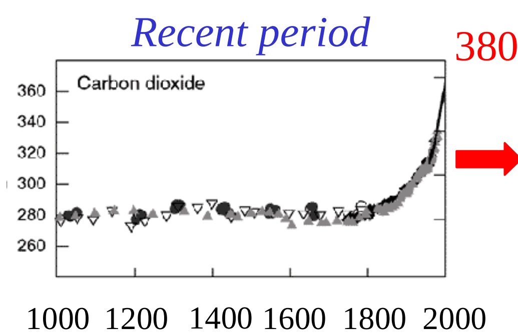
Introduction

Motivation of the study

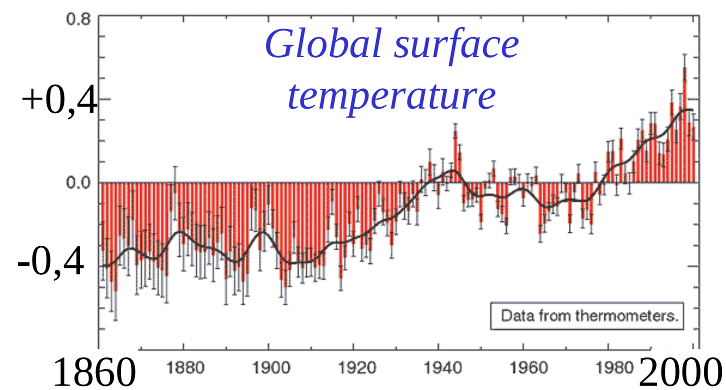
CO_2 is one of the main greenhouse gases.



Human activities are responsible for additional CO_2 emissions.



Additional greenhouse effect



The increase of atmopheric CO_2 concentration is responsible for 50% of the additional greenhouse effect.

It is essential to model the future evolution of CO_2.

Necessity of understanding the processes which governs its evolution.

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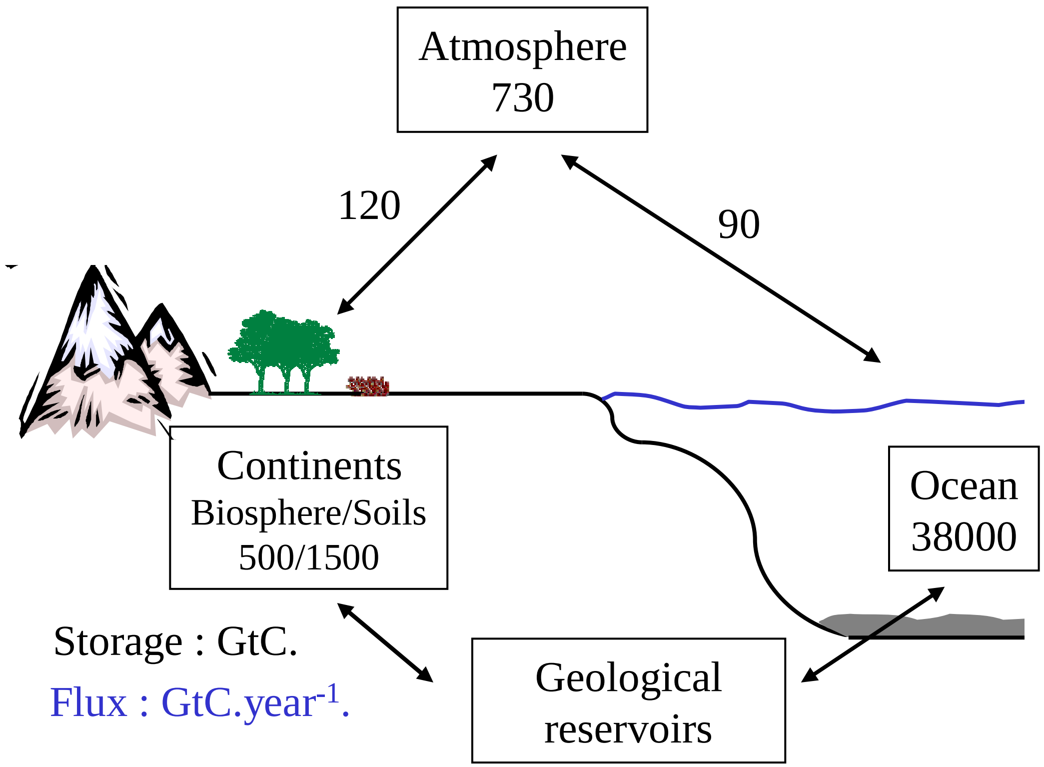
CO_2 is cyclically exchanged between several reservoirs.

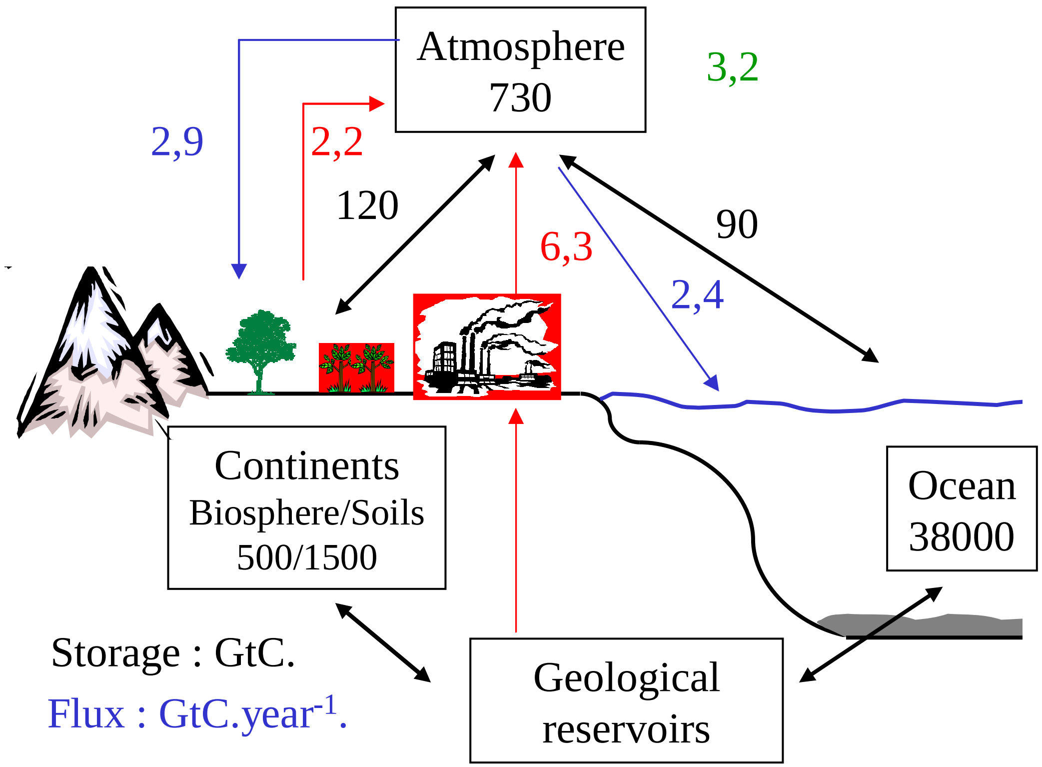


Storage : GtC.

Flux : GtC.year^{-1}.

CO_2 is cyclically exchanged between several reservoirs.

Human activities perturbs the natural carbon cycle.

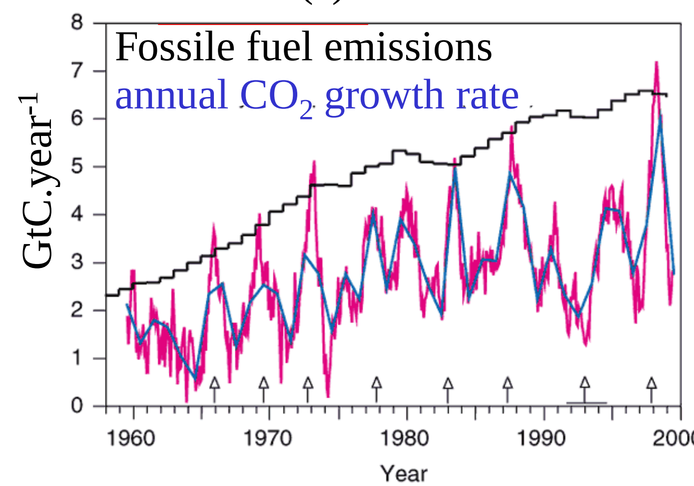


Anthropic CO_2 sources :

- fossile fuels combustion
- agricultural changes
- cement production

Surface sinks:

- ocean
- continents (?)



In order to model the future evolution of atmospheric CO_2, it is essential to understand CO_2 sources and sinks.

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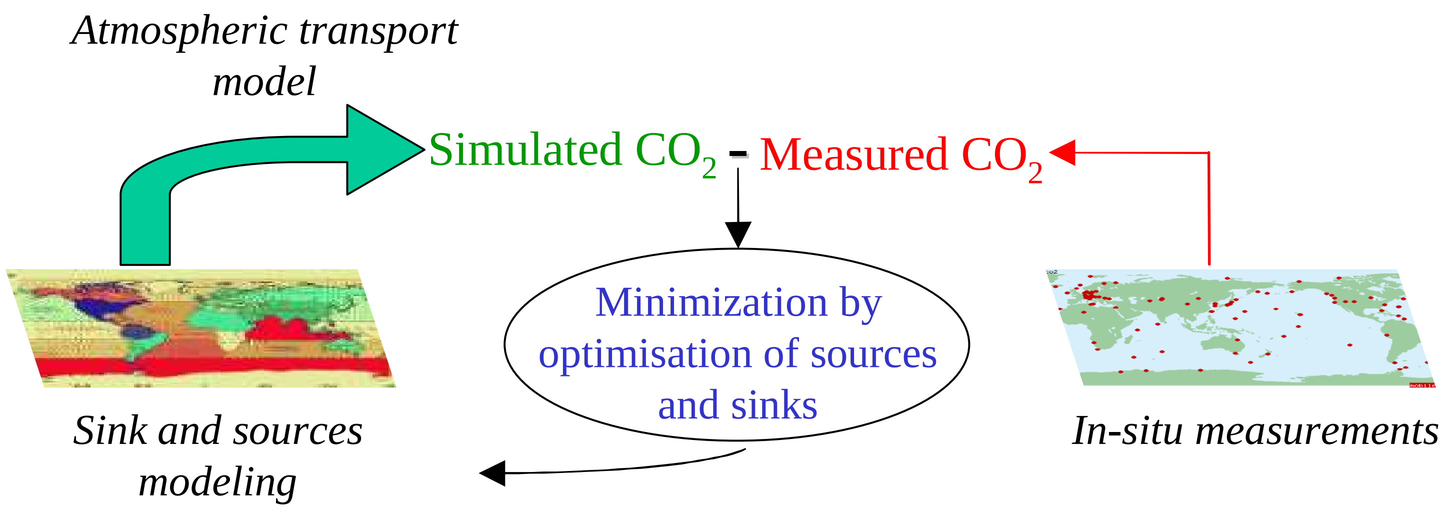
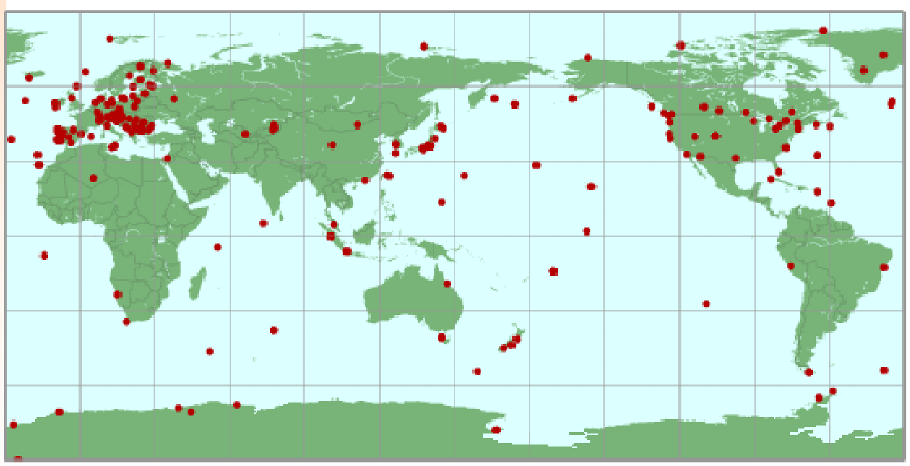
Top down approach :





Map of the WDCGG surface observation network

Uneven and partial spatial coverage

Space observations,which are global and continuous, should help to constrain the problem

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Introduction

CO_2 from space

Many instruments become available to study CO_2 from space.

Flying			
TOVS (HIRS+MSU)	Vertical sounder	thermal IR+ MW	1978
AIRS + AMSU	Vertical sounder	thermal IR + MW	2002
SCIAMACHY	Differential absorption	NIR	2002
Scheduled			
IASI + AMSU	Vertical sounder	thermal IR + MW	2005
OCO	Differential absorption	NIR	2007
Under study			
	Active methods		

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Many instruments become available to study CO_2 from space.

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Under study				
		Active methods		

The feasability of measuring CO_2 from space has been proven with the low spectral resolution instruments TOVS flying onboard the NOAA polar satellites since 1978 [*Chédin et al.* 1999, 2002, 2003].

Four years of observations (Juillet 1987-Juin 1991) of tropospheric CO_2 have been retrieved in the tropics, with an estimated precision of 3 ppmv and a spatial resolution of 15°×15°.

à Extension to the second generation AIRS instrument.

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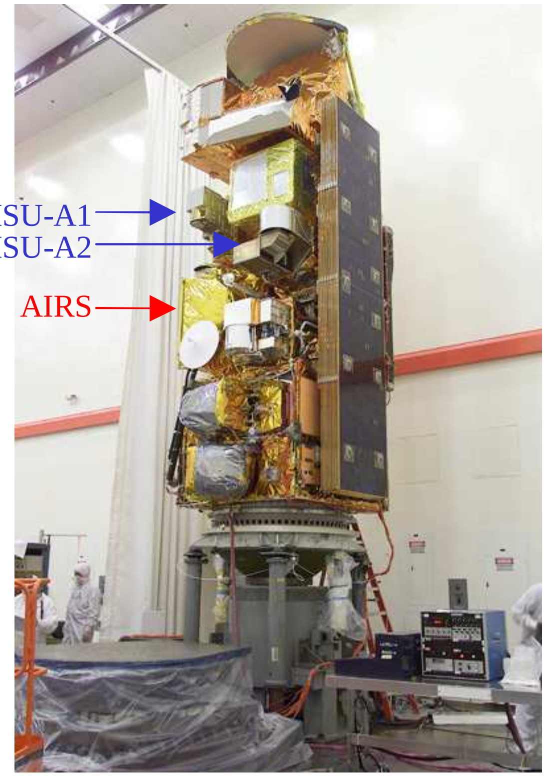
Observation from space

In this study, we use two vertical sounders flying onboard the Aqua spacecraft.



- Polar satellite afternoon (13H30).
- Date of launch: 4 May 2002.
- First component of A-train constellation.
- Six instruments dedicated to the atmosphere :
  AMSR-E MODIS CERES AIRS AMSU HSB

Atmospheric Infrared Sounder
2378 IR channels

Advanced Microwave Sounding Unit
15 MW channels

LMD stores AIRS/AMSU data since April 2003 with the highest spatial resolution available.

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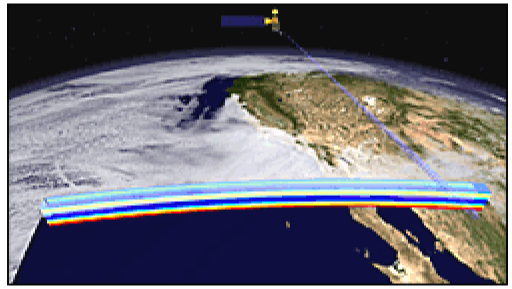
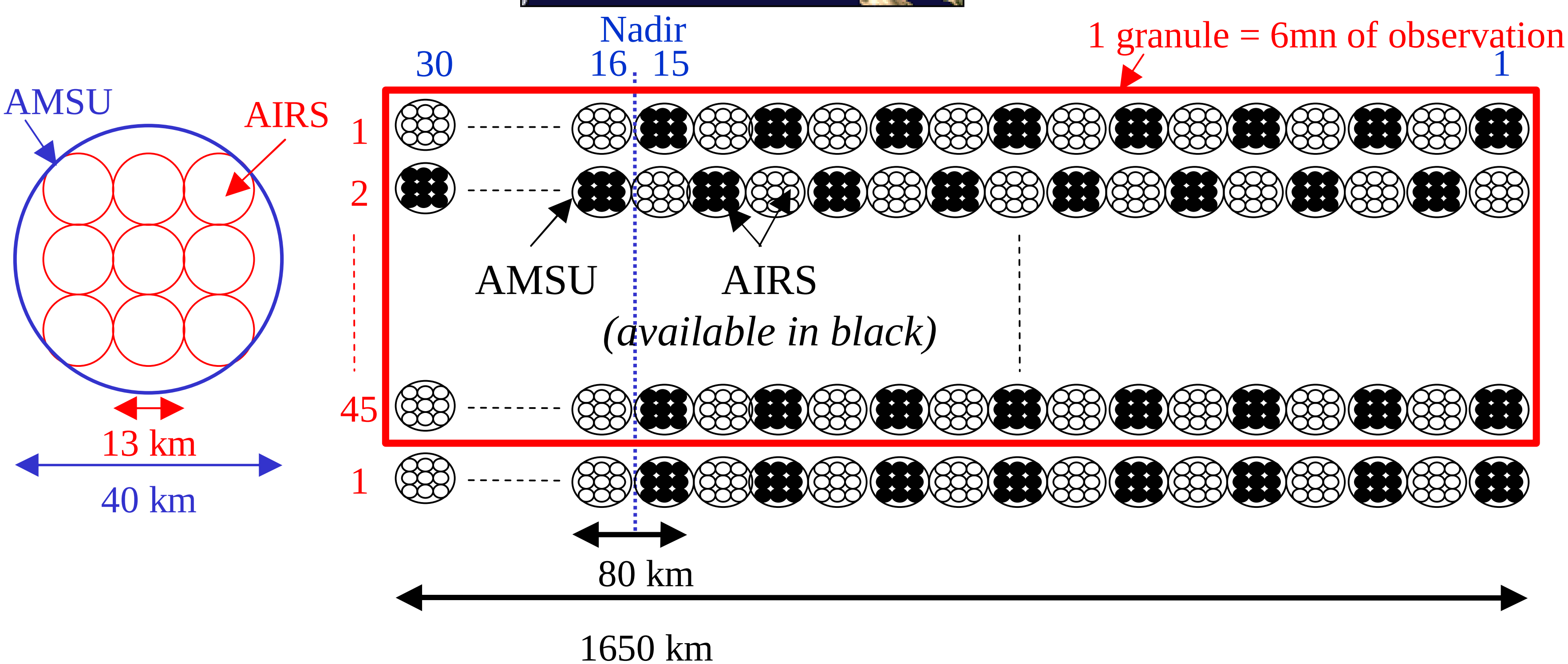
The AIRS archive at LMD





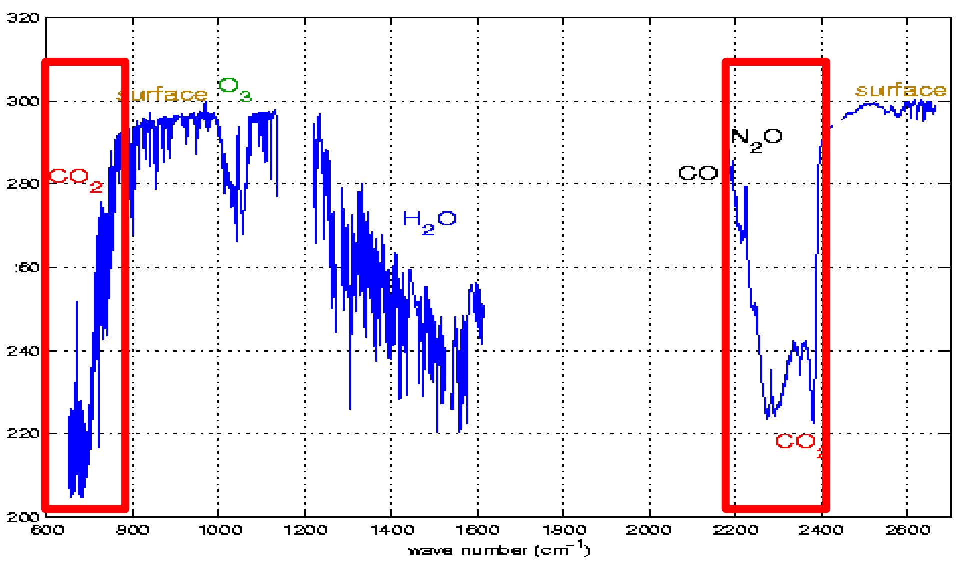
AIRS data are distributed on a daily basis by NOAA/NESDIS.

April-October 2003 (night)
Since end of December 2003 (day and night)

→ 7 months of observations sharing common characteristics

AIRS and AMSU sounders

T_B



15 µm

4.3 µm

AIRS Spectral characteristics :

- 2378 channels (324 distributed).
- three IR bands (from 650 to 2800 cm^{-1}).
- Spectral resolution: $\lambda/\Delta\lambda$=1200
- Instrumental noise: 0,2-0,3 K at 250 K.

AMSU-A Spectral characteristics :

- 15 channels between 15 and 90 GHz.
- Instrumental noise: 0,25 K for the 55 GHz channels

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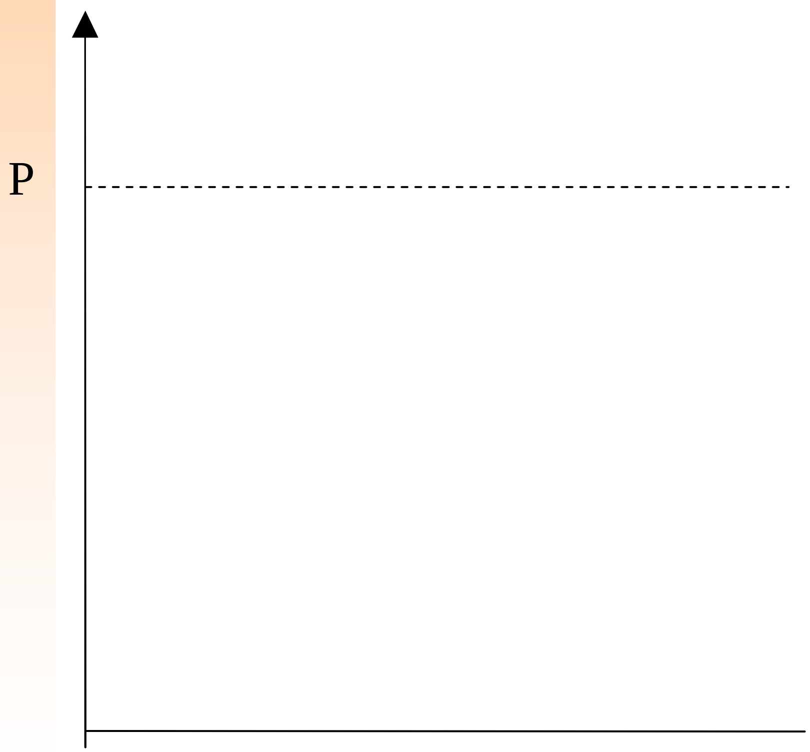
Vertical sounders measure the radiation (in terms of brightness temperature) emitted by the system Earth/atmosphere at different frequencies with a near-nadir viewing angle



$$I(\nu) =$$

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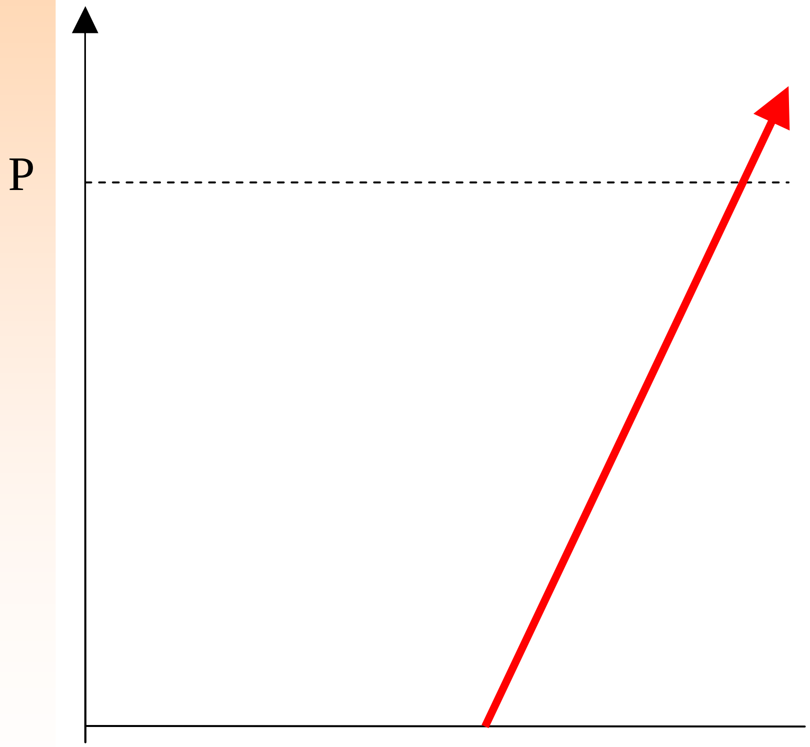

$$I(\nu) = \quad \varepsilon_s \tau_s B(\nu, T_s)$$

Observation from space

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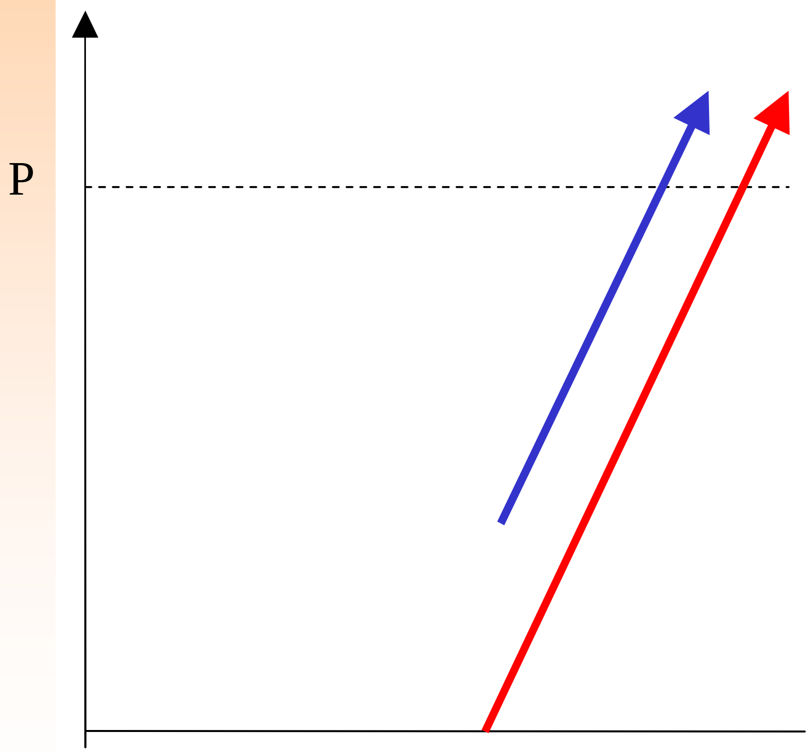
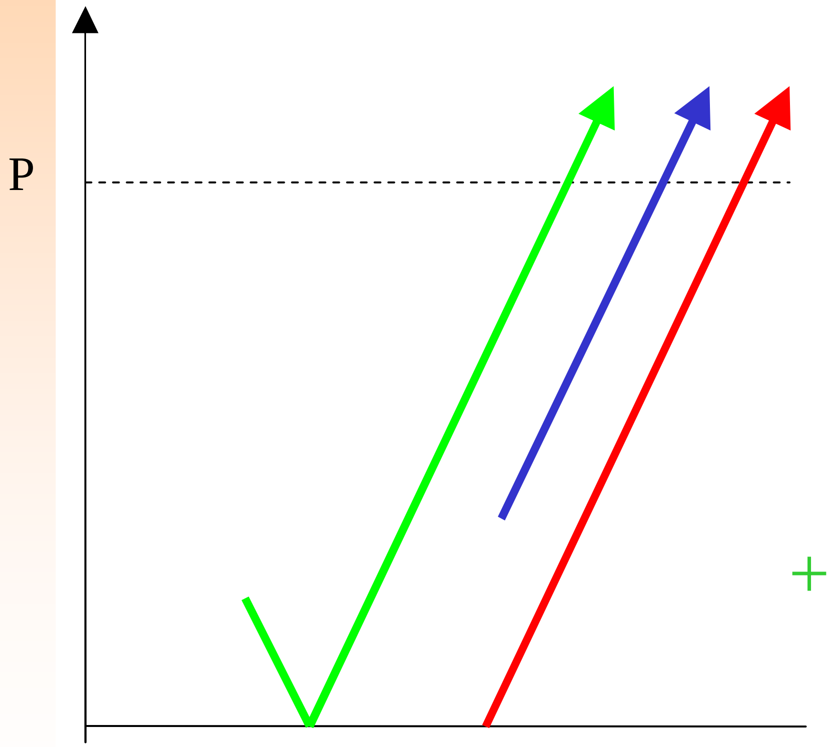


$$I(\nu) = \varepsilon_s \tau_s B(\nu, T_s)$$

$$+ \int_{\ln P_s}^{-\infty} B_\nu\left[\nu, T(\ln P)\right] \frac{\partial \tau(\nu)}{\partial \ln P} \, d \ln P$$

Vertical sounders measure the radiation (in terms of brightness temperature) emitted by the system Earth/atmosphere at different frequencies with a near-nadir viewing angle

(equations valid for a plane parallel atmosphere, scattering free, local thermodynamical equilibrium)



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$$+ (1-\varepsilon_s)\tau_s \int_{-\infty}^{\ln P_s} B[\nu, T(\ln P)] \frac{\partial \tau'(\nu)}{\partial \ln P} d \ln P$$

Vertical sounders measure the radiation (in terms of brightness temperature) emitted by the system Earth/atmosphere at different frequencies with a near-nadir viewing angle

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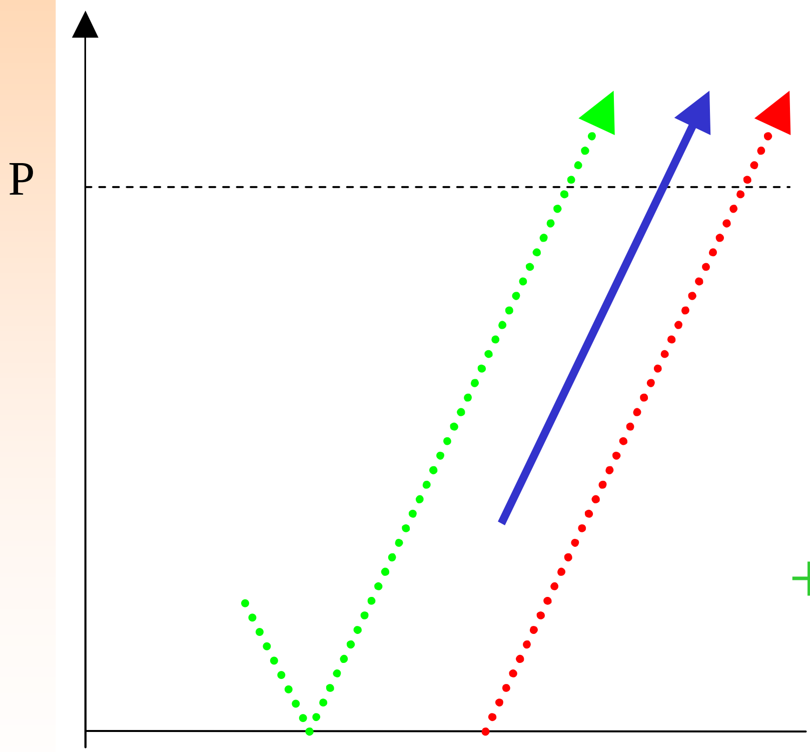
Restriction to channels who don't see the surface



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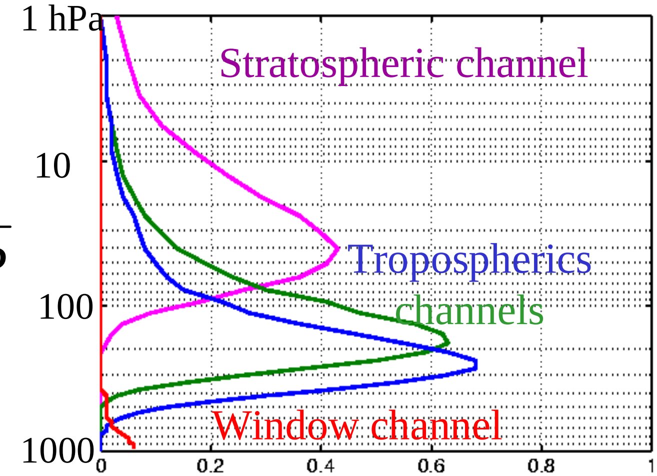
Observation from space

$$I(\nu) = \int_{\ln P_s}^{-\infty} \underbrace{B_\nu\left[\nu, T(\ln P)\right]}_{} \underbrace{\left(\frac{\partial \tau(\nu)}{\partial \ln P}\right)}_{} d\ln P$$

Temperature

Atmospheric composition $\dfrac{\partial \tau}{\partial \ln P}$

Weighting functions of 4 AIRS channels



If ν is chosen in the absorption band of a well mixed gas of known mixing-ratio, it can provide information on the temperature profile.

Infrared instruments CO_2 absorption bands

Microwave instruments O_2 absorption bands

IR : sensitives to T et CO_2

MW : sensitives to T

⇨ decorrelation T/CO_2.

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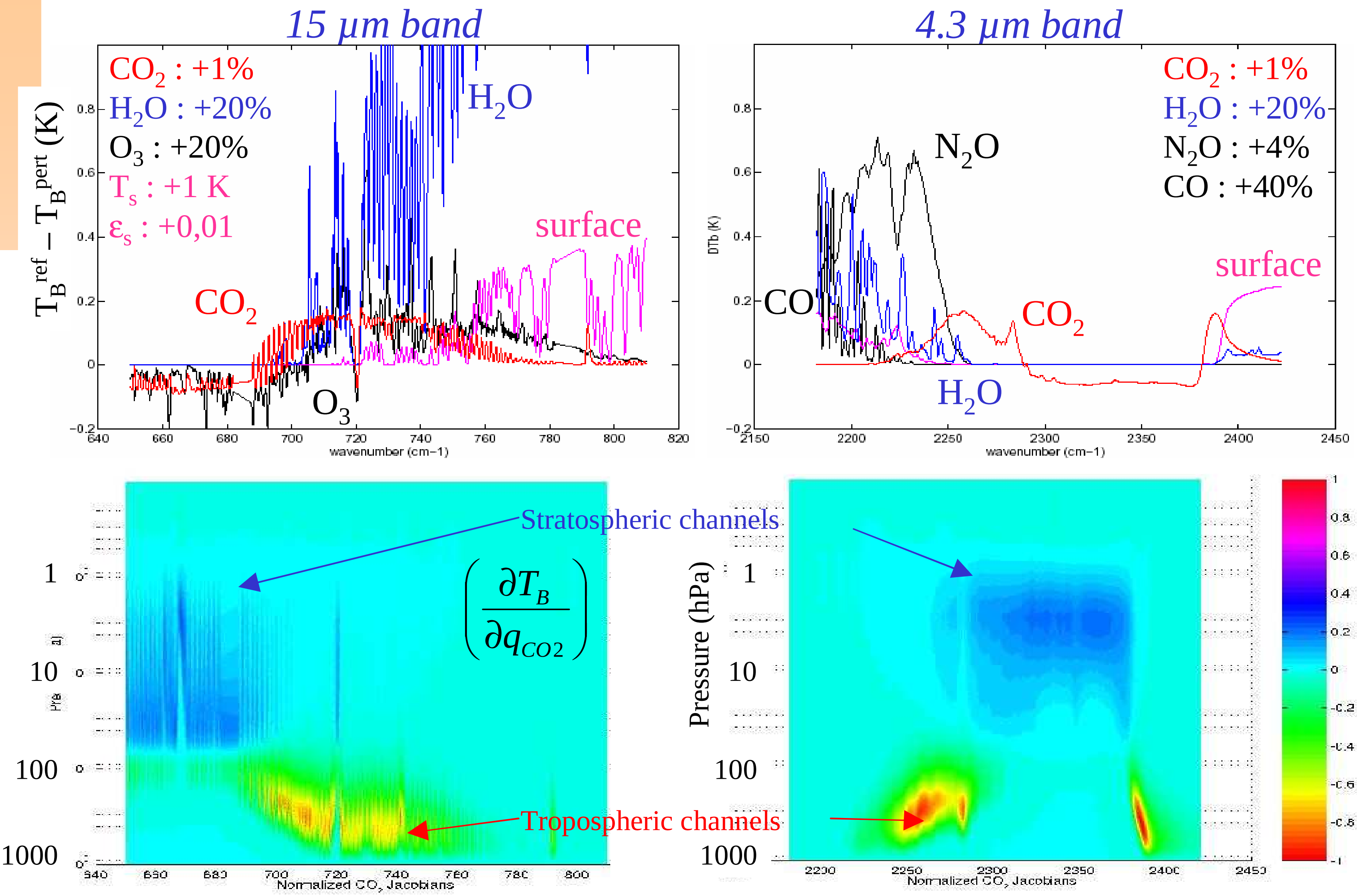
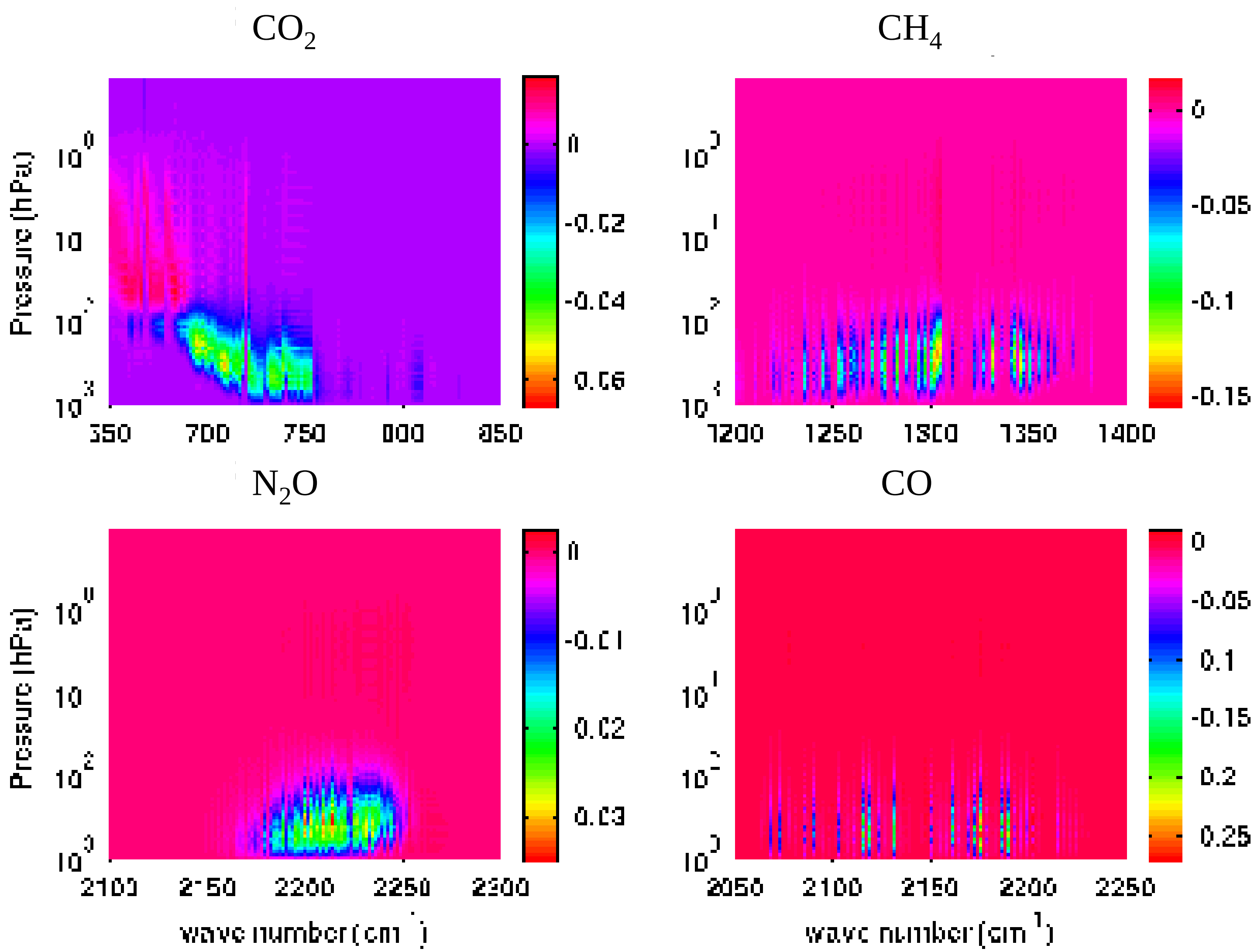
Method

AIRS and CO_2



No sensitivity to CO_2 variations in the tropopause/boudary layer.

- AIRS may be used to retrieve other trace gases.



Method

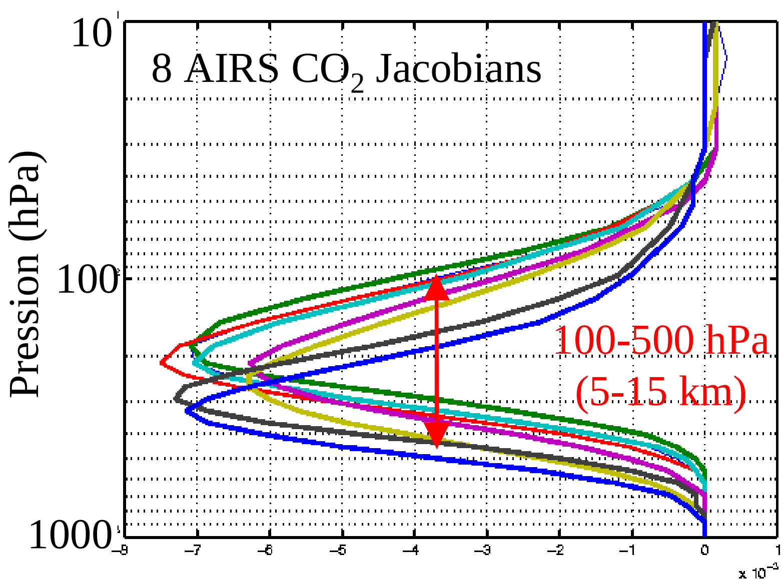
AIRS and CO_2

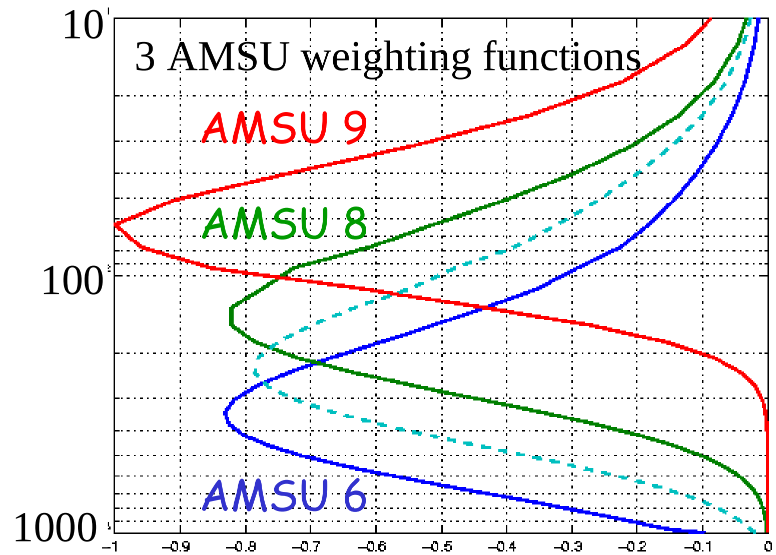
AIRS channels are selected using the OSP (Optimum Sensitivity Profile) method which is based on 3 criteria:

- CO_2 signal must be maximum.
- interferences must have the lowest influence.
- altitude of the sounding.

➡ 8 AIRS channels for CO_2 + 16 channels for CH_4, N_2O and CO.

These channels have been chosen to be distributed by NOAA/NESDIS.





Study of CO_2 in the mid-upper troposphere.

Crevoisier et al., QJRMS, 2003

Method

- A change of 1% of the CO_2 concentration induces a change of 0.04% of the signal observed on the channels.
- The signal is of the same level as instrumental noise.
- Non-linearities makes it difficult to solve this inverse problem.

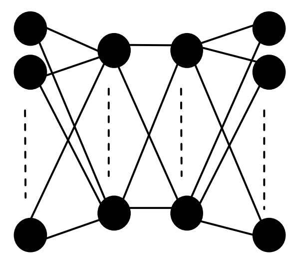
→ Use is made of a non-linear inference scheme based on neural networks.

T/CO_2 ← 8 T_B AIRS

T ← 3 T_B AMSU

6 T_B(AIRS)-T_B(AMSU)

Inputs



Outputs

8 T_B^{qref}-T_B^{qCO2}

q_{ref} - q_{CO2}

- The retrieval is limited to the tropical zone:
  - greater tropospheric temperature stability.
  - stronger convective vertical mixing from surface to mid-troposphere.
  - need of observations in this part of the globe.

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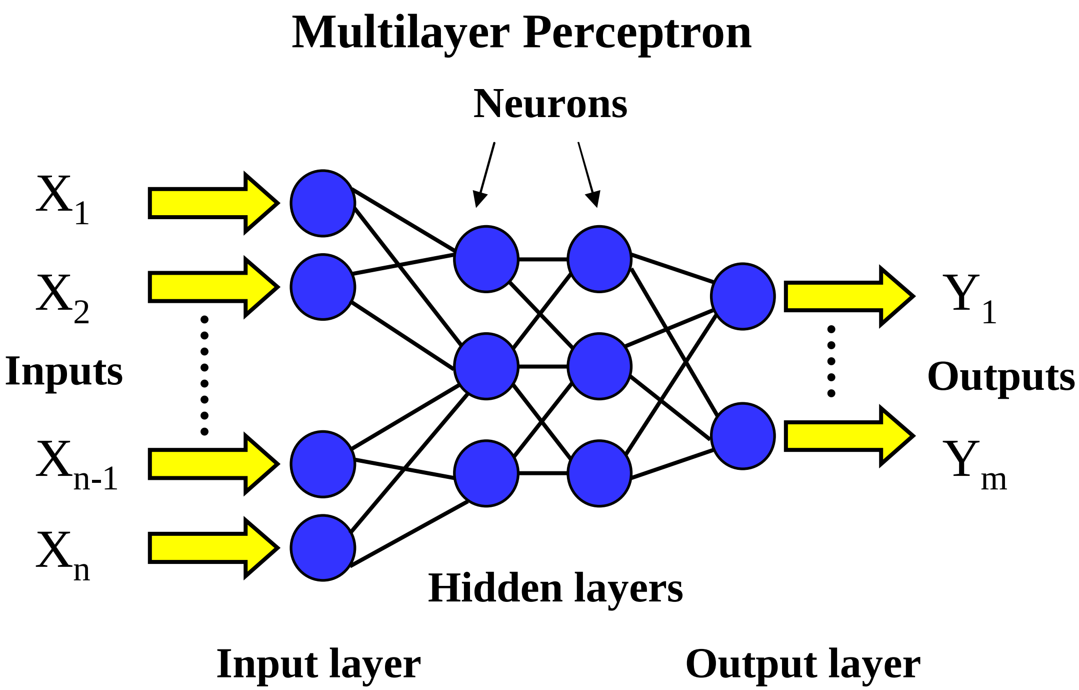
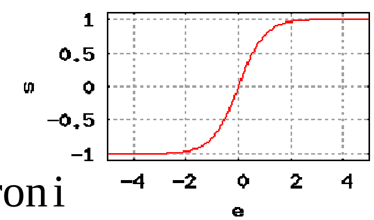


$$s_i = f\left(\sum_j w_{ij} e_j\right)$$



s_i output of neuron i

e_j input of neuron i from neuron j

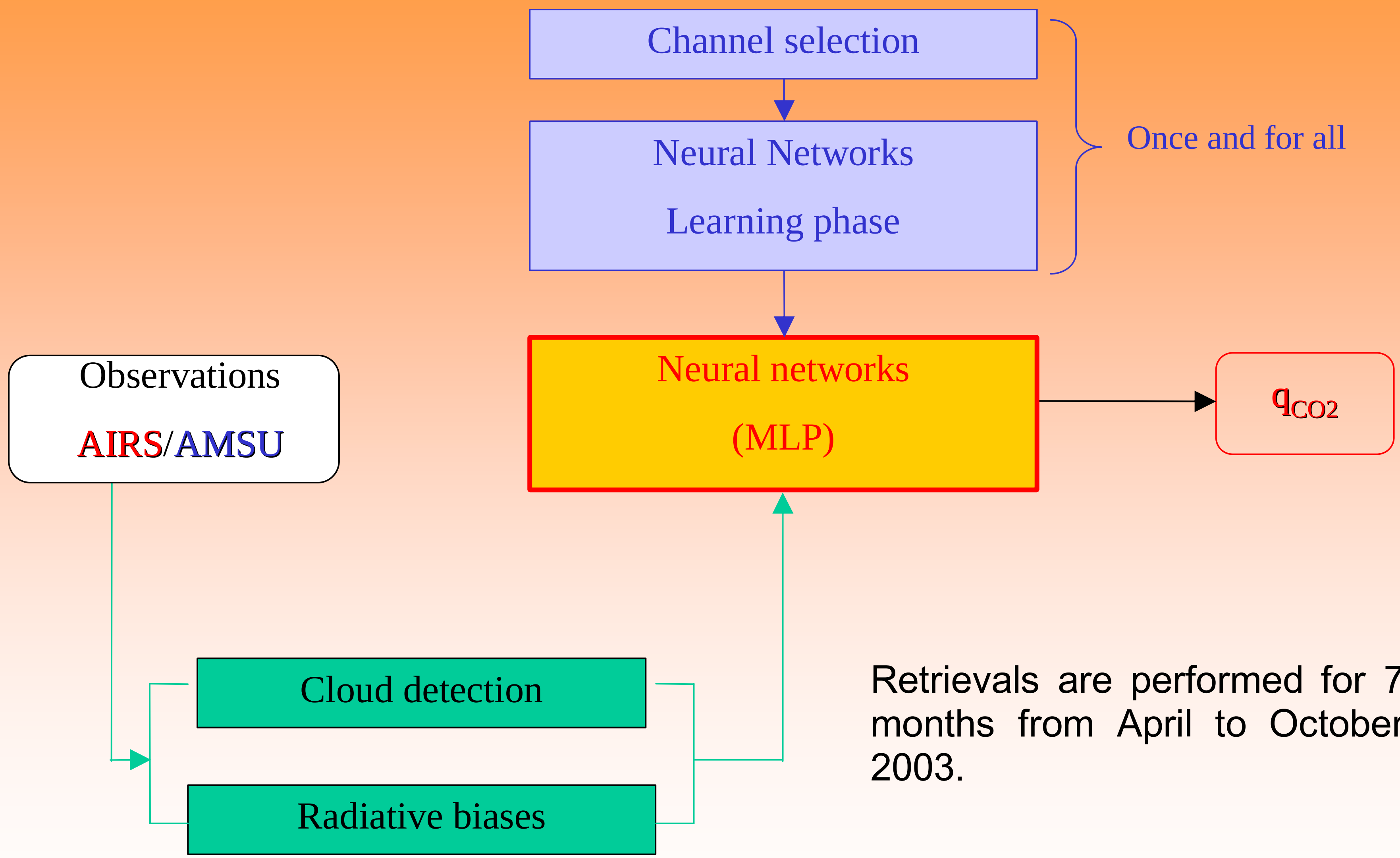
w_{ij} weight

f sigmoid function

Purpose : approximation of complex function
given a set of input and outputs (**X**[i],**Y**[i]), the learning dataset

Training of the network : determination of the weights using
a gradient descent algorithm called «backprogation» (Rumelhart)

Retrieval scheme



Retrievals are performed for 7 months from April to October 2003.

Crevoisier et al., GRL, 2004

Description of the method

Looking for clear sky

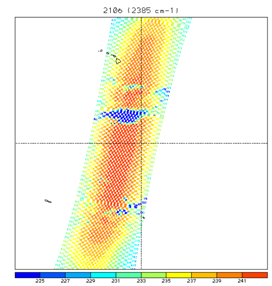
- Three kind of tests are used : $T_B^1 - T_B^2 < \xi$

  - 8 T_B(AIRS) – T_B(AMSU)

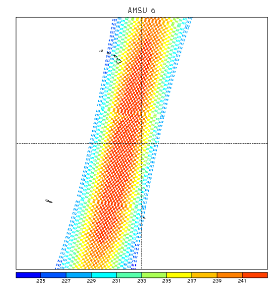
    Sensitive to clouds

    Unsensitive to clouds

AIRS



AMSU



  - 5 T_B(AIRS) – T_B^{reg} Regressions from T_B(AMSU)

  - 2 T_B(AIRS) – T_B(AIRS) Windows channels

Si $T_B^1 - T_B^2 < \xi$, then clear sky

else cloudy

These clear sky tests have been successfuly validated against MODIS cloud detection for P≤ 750 hPa

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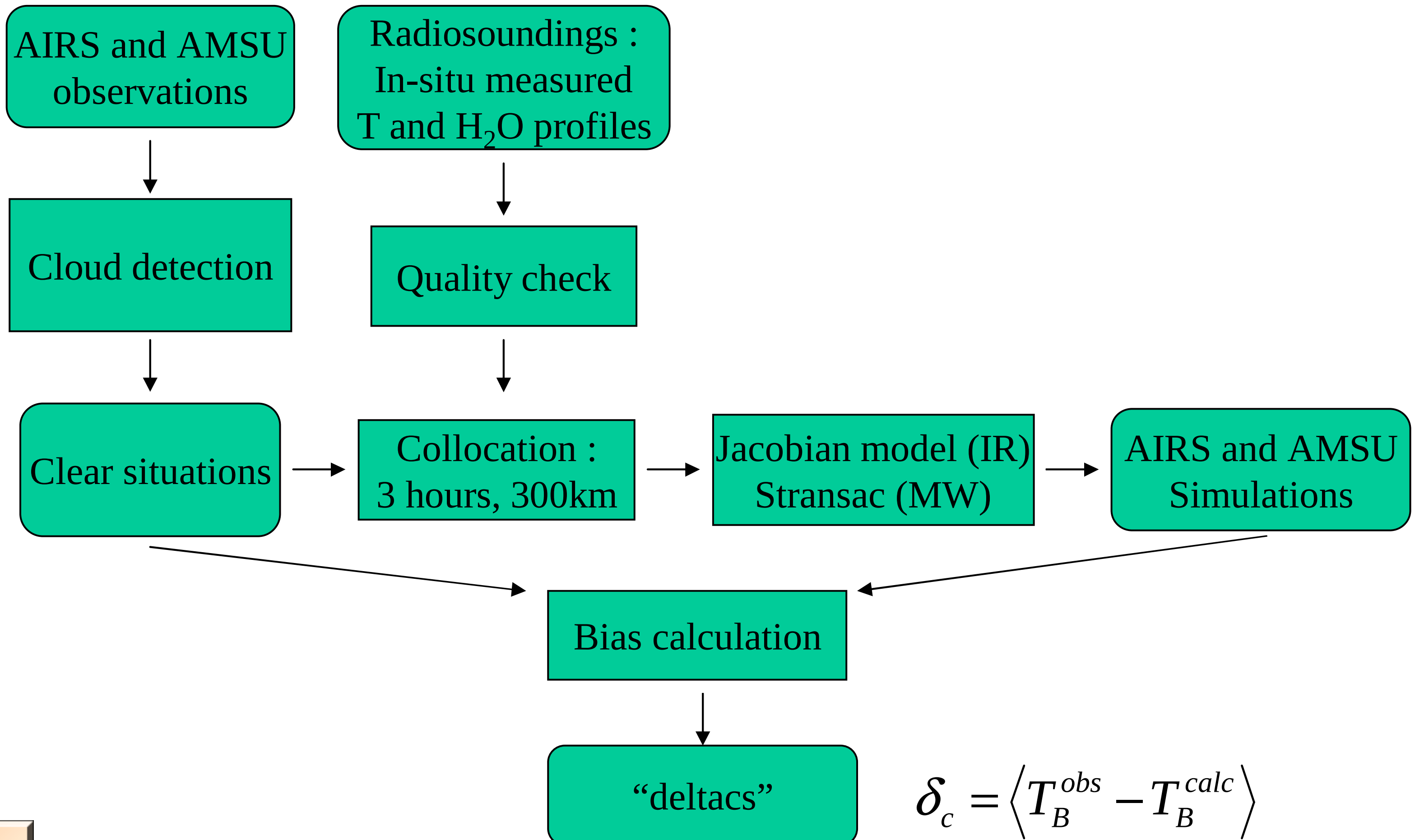
Description of the method

Radiative biases calculation

Before applying the neural networks to observed AIRS and AMSU radiances it is necessary to correct for possible biases linked to calibration and radiative transfer error



$$\delta_c = \left\langle T_B^{obs} - T_B^{calc} \right\rangle$$

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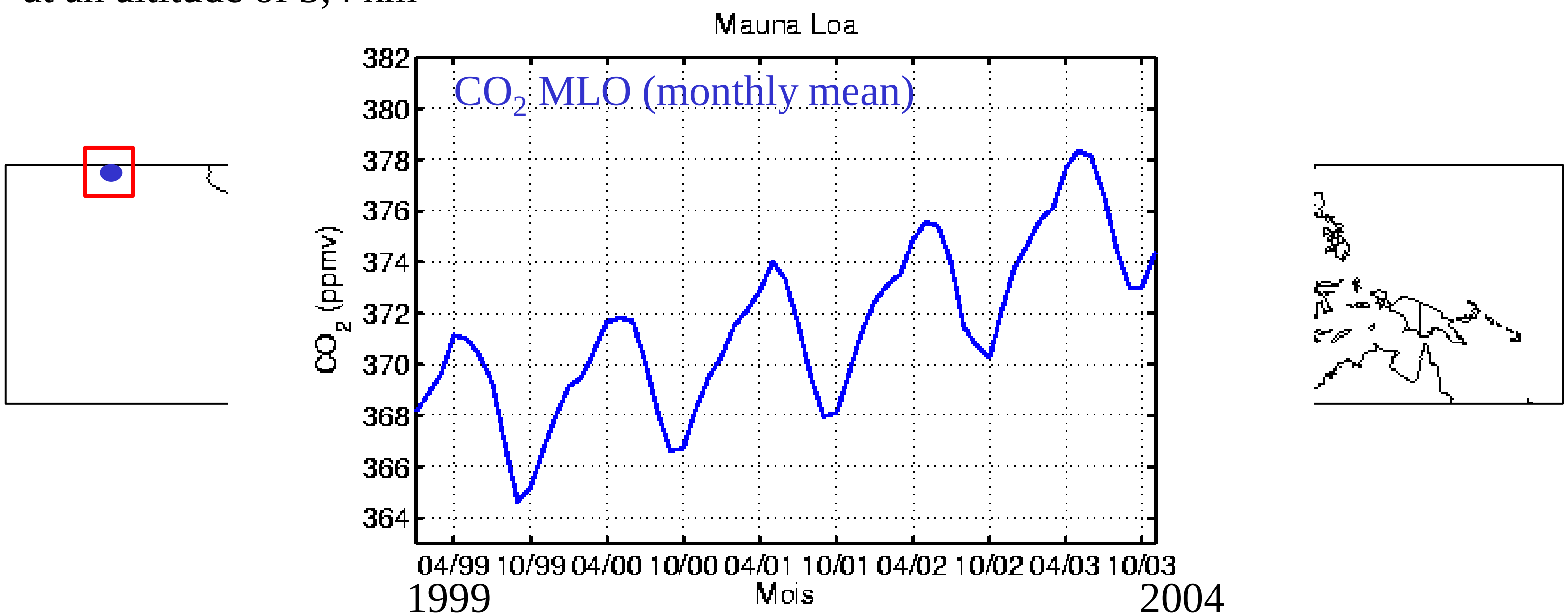
- Comparison with in situ observations made at the surface

Mauna Loa (Hawaï)
Daily measurements of CO_2 since 1958
at an altitude of 3,4 km

AIRS retrievals are averaged on a monthly basis over a 5°×5° box centered on MLO.



Study of the results

Seasonal variations

- Comparison with in situ observations made at the surface

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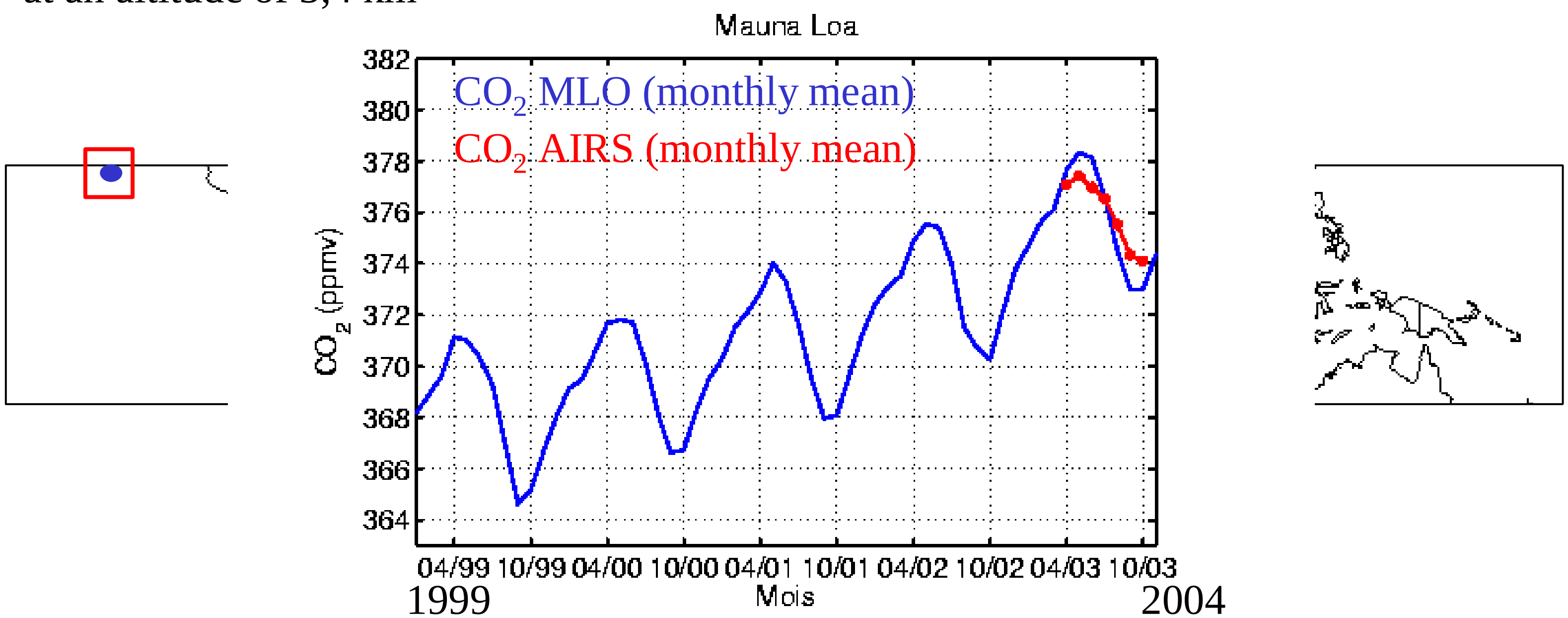

Lower amplitude (3,4 km □ 5-15 km) but good agreement between both sets.

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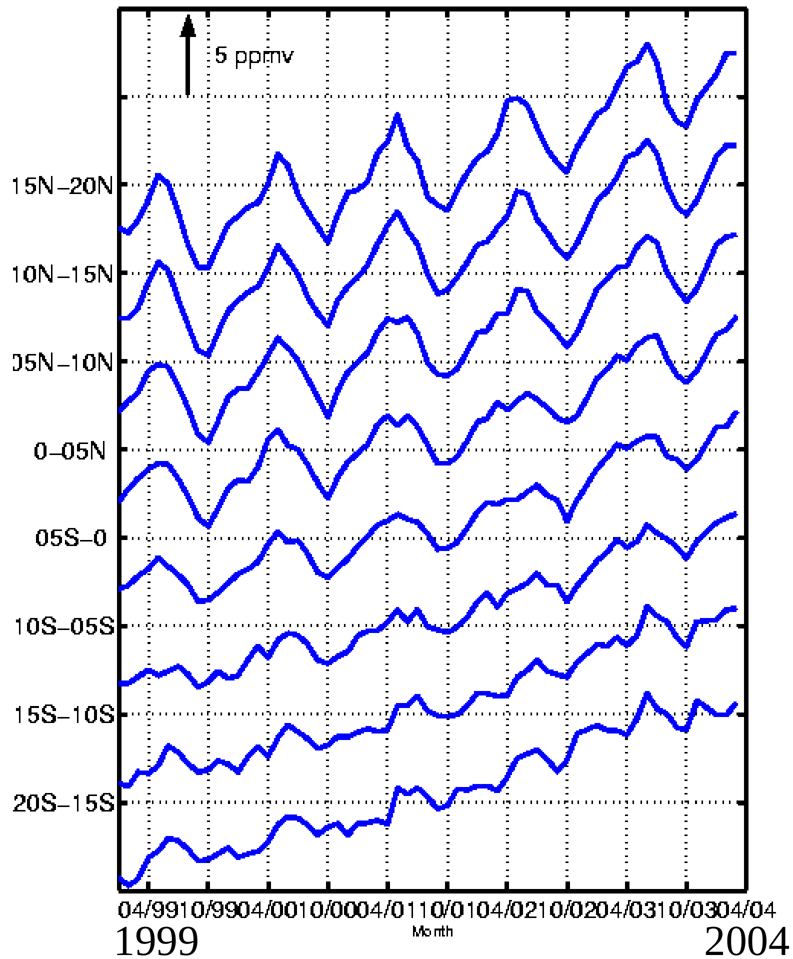
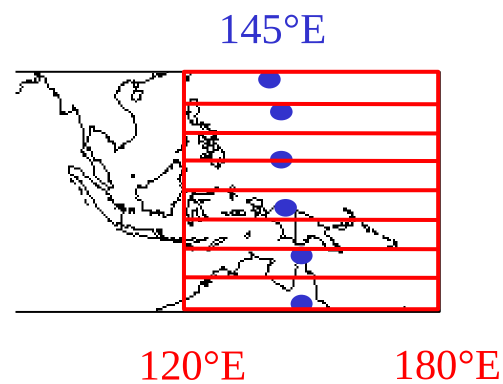
- Comparison with aircraft measurements :

Since 1991, JAL aircrafts have been equiped to measured CO_2.

Altitude : 8-10 km (inside the zone 5-15 km seen by AIRS/AMSU).

One to two measurements per month.





Average on 8 latitudinal bands from 20S to 20N

[Matsueda et al. 2004]

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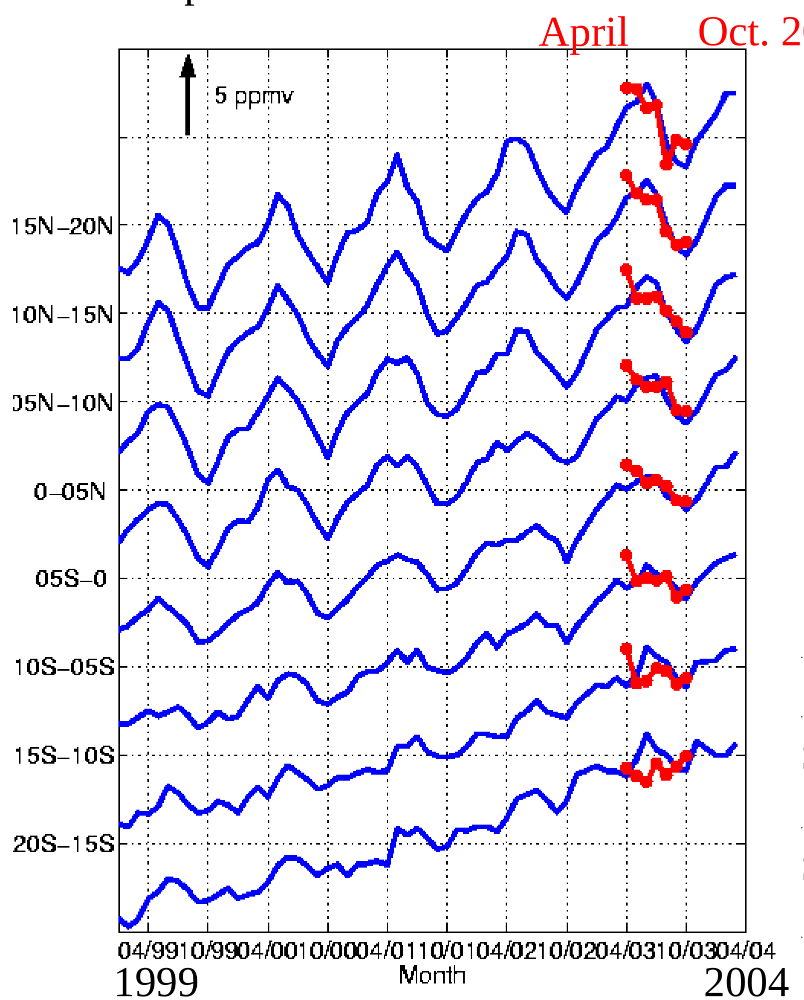
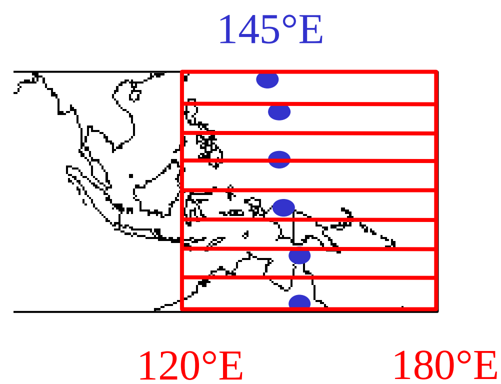




Average over 8 latitudinal bands from 20S to 20N

[Matsueda et al. 2004]

- Good agreement.
- Decrease from July to September.
- Double seasonal cycle in the South.
- April ?

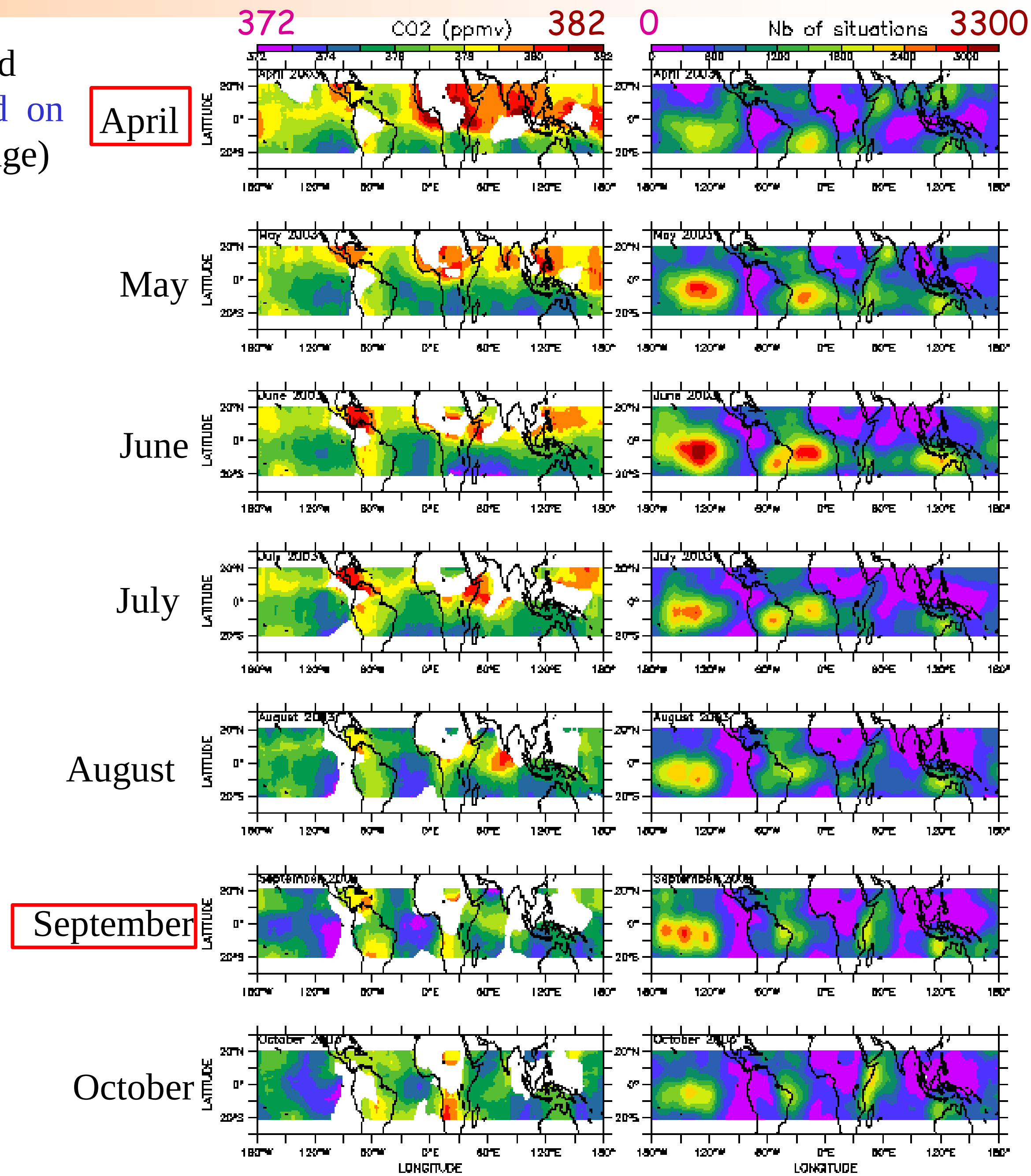
Study of the results

The retrievals are now averaged
-over 15°×15° boxes centered on the 1°×1° boxes (moving average)
-on a monthly basis
-night time
-from April to October 2003.

Study of potential interferences

Two « test » months

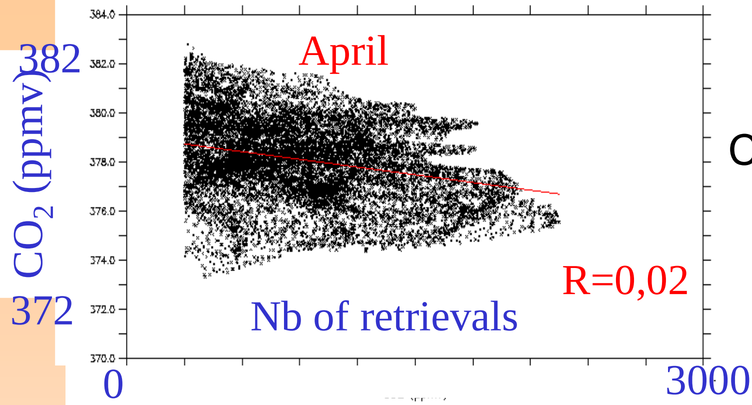
Geographical distributions



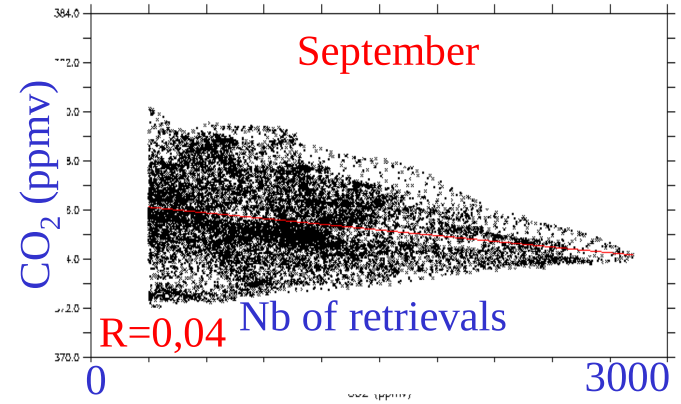
Study of the results

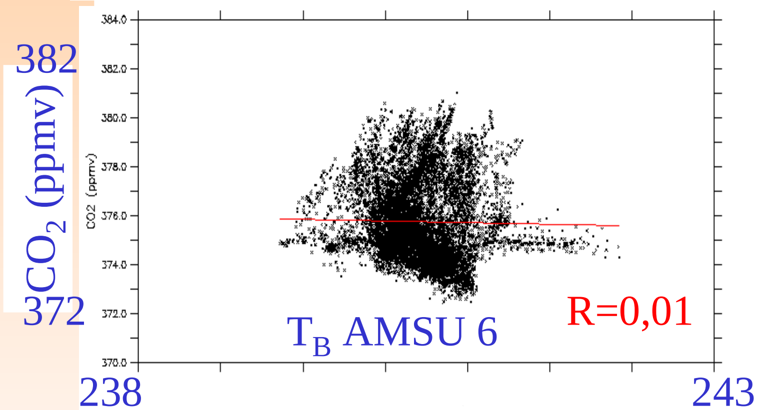
Geographical distributions

Study of the correlations

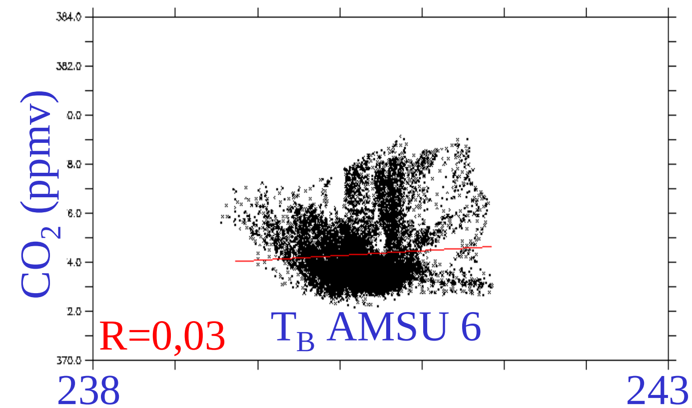


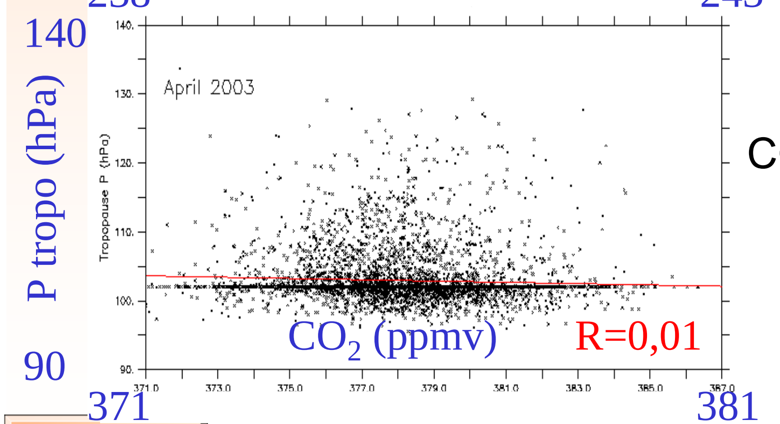
CO_2/nb of retrievals per box



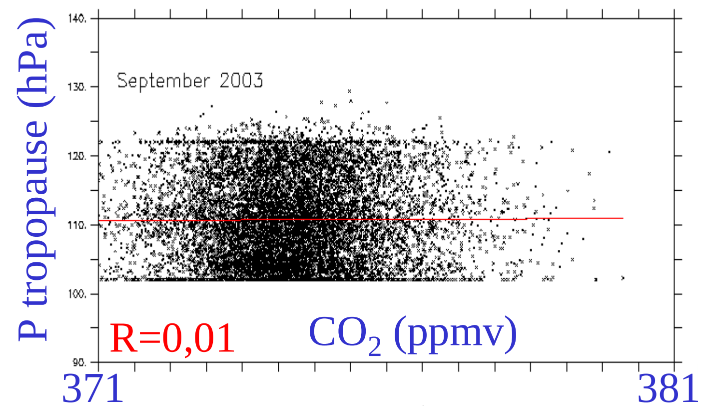


CO_2/temperature





CO_2/tropopause height



The NN have successfully decorrelated T and CO_2.

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IPSL

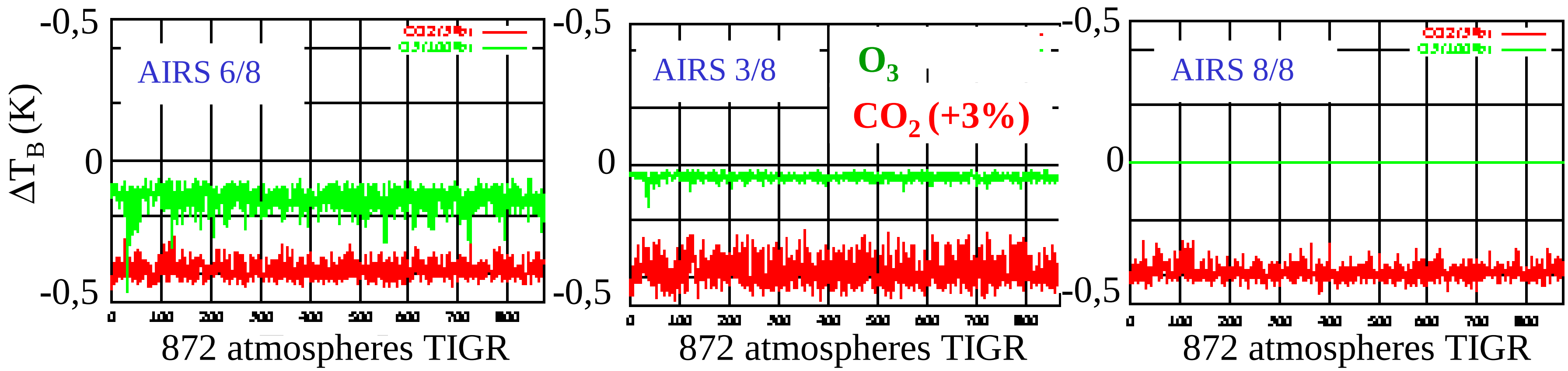
Sensitivity of neural networks :

The 8 AIRS channels have been selected for their weak sensitivity to interferences.

However, they are still sensitive to other signals (eg: ozone). Thus, we must verify the impact of an ozone perturbation on CO_2 retrievals.

Study: on a representative set of atmospheres, we make a perturbation of O_3 of 100% between 0 - 16 km.

Answers of 3 out of 8 AIRS channels



The T_B are presented to the NN.

→ The output error obtained is 0,13 ppmv (mean) and 0,36 ppmv (std).

This weak impact is due to:

- the low sensitivity to ozone.
- the distinct behaviour: CO_2 signal is constant / ozone signal varies.

- Study of the geographical variations :

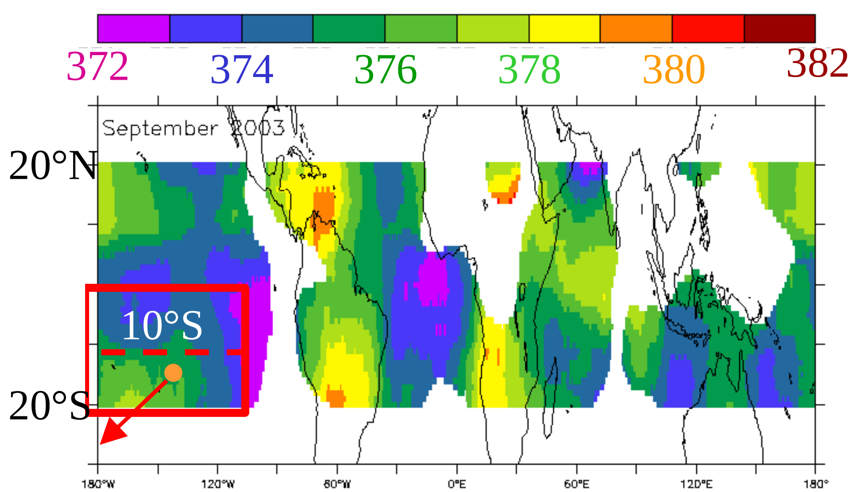
The validation of CO_2 geographical distribution is hard due to the lack of information on this gas.

A few aircraft campaigns, always limited in both time (a few months) and space, have measured trace gases in the troposphere. Unfortunately, CO_2 was not systematically studied (as opposed to CO).

Example of PEM-T [Vay et al. 1999] :

- 110°W-170°W ; September 1996.
- Between 6 and 12 km, the highest values of CO_2 were observed in the South, below 10°S, from Tahiti to New-Zealand.
- But no decrease in the East of the Pacific…

CO_2 AIRS 2003 (ppmv)



Study of the results

Geographical distributions

April

May

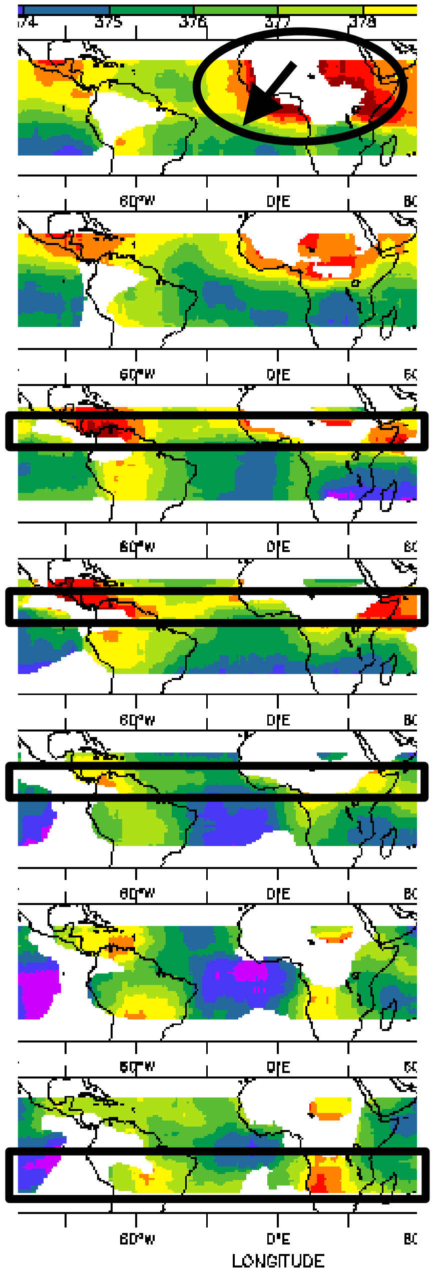
June

July

August

September

October



CO$_2$ AIRS (ppmv)

Biomass burnings

Emissions of CO_2, CO, O_3, aerosols, …

Mainly in dry tropical regions.

➡ seasonality linked to dry seasons in both hemisphere:

- Dec.-Fev. : North.
- June-Sept. : South.

In April : central Africa [*Barbosa et al.* 1999] + expulsion in the « Golfe de Guinée » [*Baudet et al.* 1990]

Summer: [0;10°N].

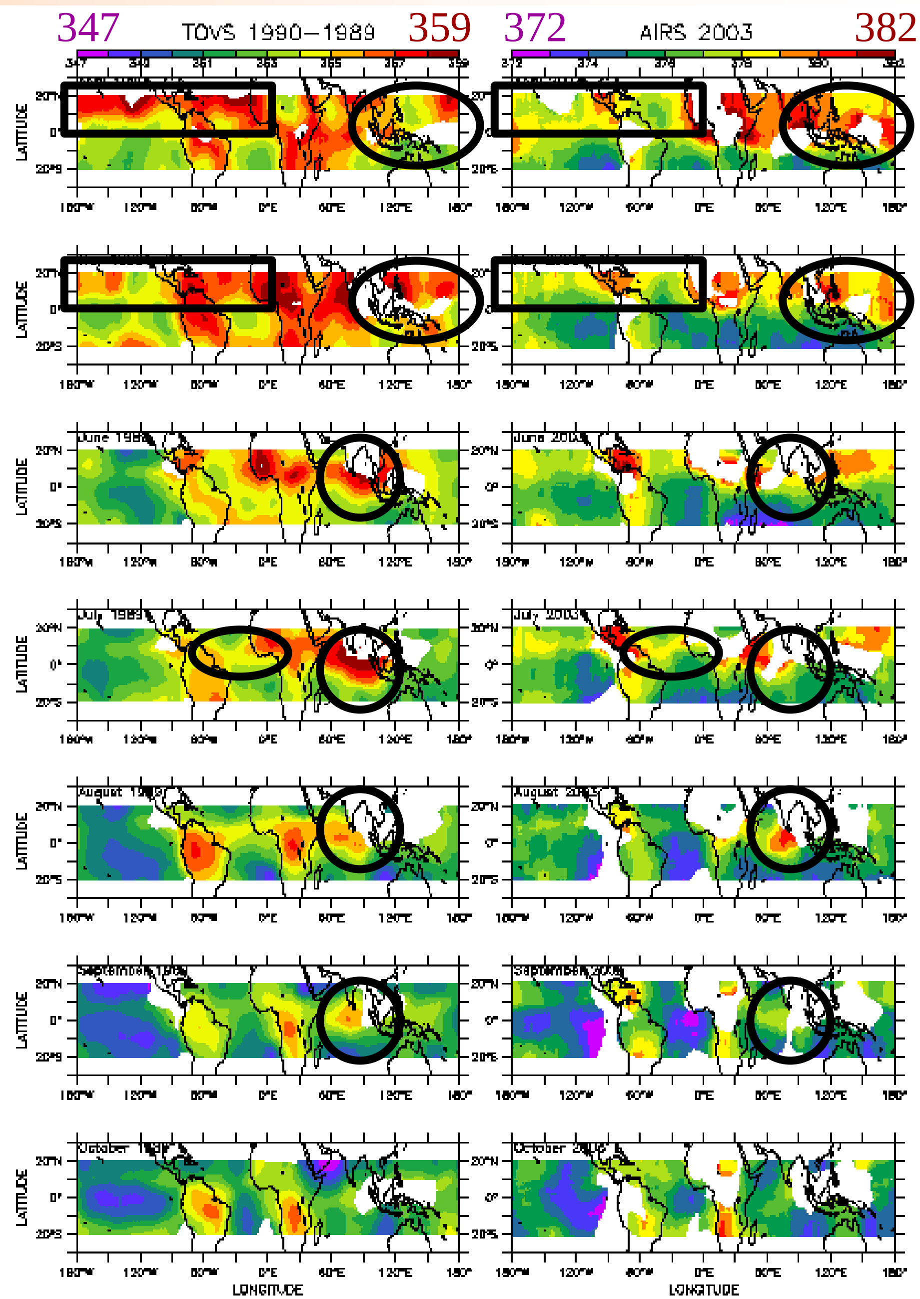
In October [*Bremer et al.* 2004]

- South Africa and America.
- plum between both continents.
- expulsion forward the Réunion Island

Qualitative agreement with AATSR fire counts and CO MOPITT measurements

Study of the results

Geographical distributions



Comparison with TOVS :

NOAA10 : July 1987-June 1991

Comparison with April-May 1990 and June-Oct. 1989 (weak El Nino)

Given the interannual variations, both structures are similar:

- Pacific.
- Indian Ocean.
- Atlantic ocean.
- Biomass burnings.

Some differences :

- North in April and May (O_3 ?).
- Dynamic.

Study of the results

Comparison with transport model outputs (TM3 and LMDz in the framework of the COCO project) :

[*Y. Tiwari*, *MPI*, private com.].

- model inputs:
  - Sources: 2002.
  - Winds: ECMWF 2003.
- AIRS weighting function is applied to the outputs that are averaged following the same method as for AIRS retrievals.

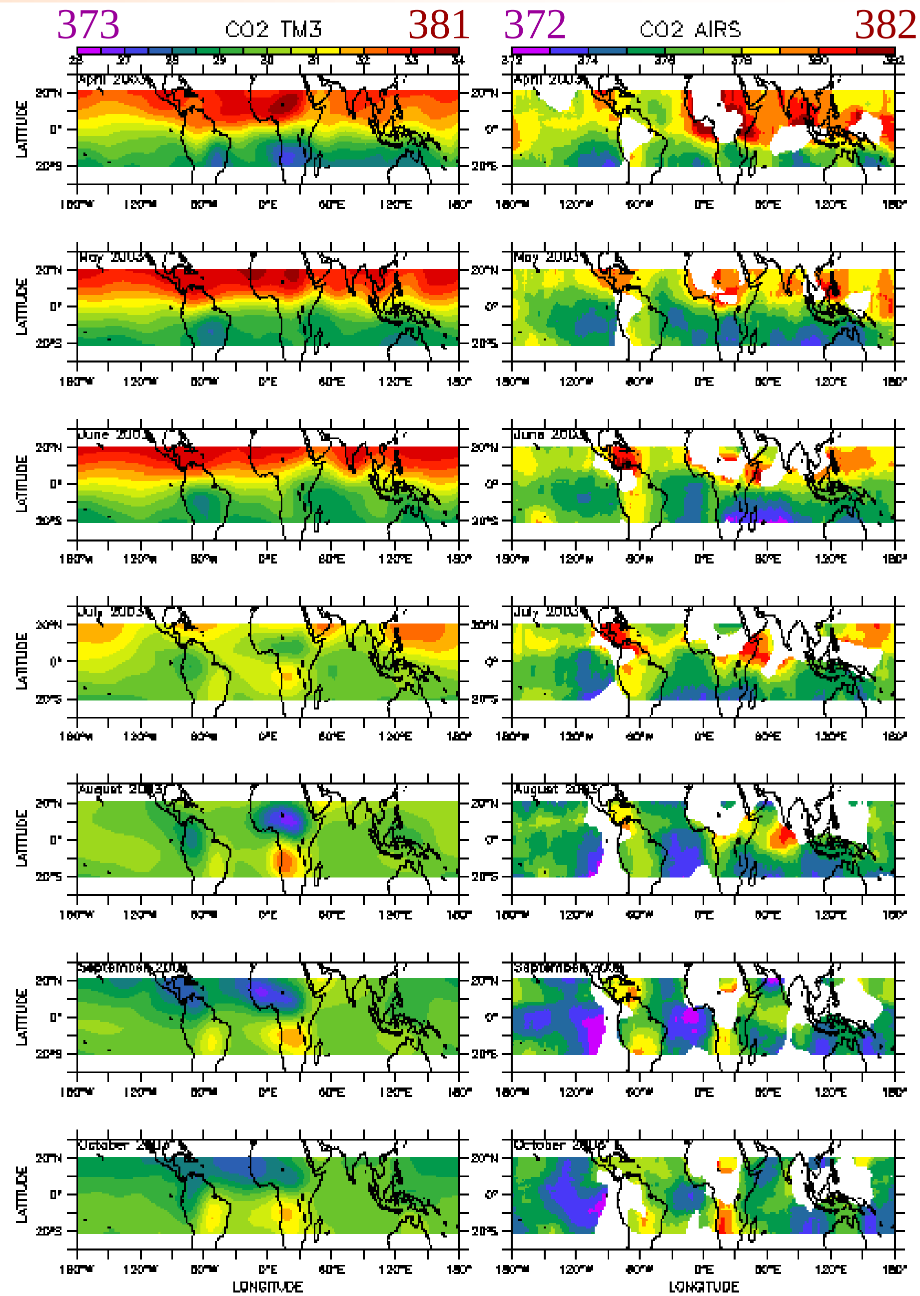
➡ The models are zonal with very low longitudinal variations.

- Lower dynamic.
- Same fire locations.

Origin of these differences ?

➡ Comparison with aircraft measurements (LMD/LSCE).

Geographical distributions



PRESENTATION OUTLINE

- Why is it interesting to measure CO_2 from space ?
- Which instruments are available for this purpose ?
- Presentation of the AIRS and AMSU instruments
- Radiative transfer, principles of atmospheric sounding
- Description of the retrieval method
- First results
- Conclusion, perspectives

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Conclusion and perspectives

- Realisation of an AIRS/AMSU archive.
- Channel selection:
  - OSP method for CO_2, CH_4, N_2O and CO.
    - à Extension to other instruments : IASI.
- Clear sky detection.
- Tropospheric CO_2 retrieval:
  - Extension of the TOVS NN method.
  - Tropospheric CO_2 retrieval (5-15 km), in the tropics [20°S;20°N], night time, from April to October 2003.
  - Good agreement with *in situ* measurements.
  - Monthly distribution at a resolution of 15°×15°, with a precision of 2,5 ppmv.
  - Good agreement with TOVS retrievals.
  - Transport models.

CO_2 campaigns are needed to validate the retrievals !

Conclusion et perspectives

- Extension of the method : tropospheric CO_2 in the tropics:
  - à Better computation of radiative biases.
  - à 2004.
  - à Comparaison between retrievals / aircraft campaigns / transport models.
- Extension of the method :
  - à High-latitude regions ?
  - à stratospheric CO_2 ?
- Other trace gases and instruments:
  - à CH_4 (initiated), CO, N_2O.
  - à IASI

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